

# Active Noise and Occlusion Effect Cancellation in Headphones and Hearing Aids

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**Stefan Liebich**

aus Gelsenkirchen

Berichter: Universitätsprofessor Dr.-Ing. Peter Vary  
Universitätsprofessor Dr.-Ing. Dr. med. Dr. h. c. Steffen Leonhardt

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## **AACHENER BEITRÄGE ZU DIGITALEN NACHRICHTENSYSTEMEN**

Herausgeber:

Prof. Dr.-Ing. Peter Vary  
Institut für Nachrichtengeräte und Datenverarbeitung  
Rheinisch-Westfälische Technische Hochschule Aachen  
Muffeter Weg 3a  
52074 Aachen  
Tel.: 0241-80 26 956  
Fax.: 0241-80 22 186

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# Abstract

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The perception of one's own voice is distorted when telephoning with headsets, or wearing hearing aids. The reason for this is the so-called *occlusion effect*, which occurs when ear canals are completely or partially closed by the headset or hearing aid. The occlusion causes amplification at low frequencies, and attenuation at high frequencies of one's own voice. The unnatural perception of one's own voice and of noise caused by chewing and swallowing are among the most common complaints of users. Furthermore, environmental noise might impair perception. In this thesis, both the unnatural perception of one's own voice and the disturbance by environmental noise are tackled by a novel signal processing approach.

The proposed solution solves the problem of the occlusion effect by actively emitting a compensation signal through the integrated loudspeaker. The approach is called *Occlusion Effect Cancellation* (OEC) and significantly improves the perception of one's own voice and of the acoustic environment. This novel approach combines methods of active noise cancellation (ANC, Noise Cancelling Headphone) with a personalized design. The bilateral headset contains two additional microphones per side, one inner and one outer, to acquire signals for the calculation of the compensation signals. A correctly balanced processing of the two microphone signals results in a "digital ear opening" and a much more natural perception of both one's own voice and of the environment. The extent of the digital ear opening is controllable. The system can also be operated as a noise cancelling headphone by changing the parameters to a conventional design to create an acoustic isolation from the environment.

This thesis proposes a novel robust approach based on digital filtering to solve the described problems. A combination of feedback and feedforward filter design allows for either approaching personal silence or a natural perception of one's own voice and the acoustic environment.

The main contributions are:

- Novel design concept for ANC / OEC systems which are robust w.r.t. acoustical variations of ear canals and earpiece fittings
- Novel structure for combined feedforward-feedback filters with adaptive stability control
- Analysis of variability of acoustic front-end (headset) as well as electronic back-end (digital signal processing incl. AD/DA-conversion) and implications

on ANC/OEC performance

- Real-time implementation of algorithms on a PC-sized dSPACE system as well as a mobile integrated circuit (Analog Devices ADAU 1777)
- Objective instrumental and subjective auditive evaluation of the concepts

The achieved ANC performance is comparable to that of a commercial reference system. The novel OEC algorithm revealed in both objective measurements and subjective listening tests, significant improvements of the own-voice perception.

To conclude, this thesis provides an in-depth discussion of the underlying problems of active noise and occlusion effect cancellation, design methods for digital control filters, an analysis of the implementation requirements for a real-time system as well as an evaluation based on both measurements and listening tests.

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# Contents

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<b>Abstract</b>	<b>v</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Background and Objectives . . . . .	1
1.2 Structure and Contributions . . . . .	2
<b>2 Problems and Approaches</b>	<b>5</b>
2.1 Active Noise Cancellation . . . . .	5
2.1.1 Acoustic Paths . . . . .	7
2.1.2 Variation of Acoustic Paths . . . . .	10
2.1.3 Feedback Control . . . . .	11
2.1.4 Feedforward Control . . . . .	12
2.1.5 Combined Feedforward-Feedback Control . . . . .	14
2.1.6 Accuracy Requirements . . . . .	15
2.2 Physiological Speech Production and Human Hearing . . . . .	16
2.2.1 Speech Production . . . . .	16
2.2.2 Characteristics of Speech Signals . . . . .	18
2.2.3 Human Hearing . . . . .	19
2.2.4 Own Voice Perception . . . . .	21
2.3 The Occlusion Effect . . . . .	25
2.3.1 Objective Measurements of the Occlusion Effect . . . . .	27
2.3.1.1 Measurements Based on Vocalization . . . . .	28
2.3.1.2 Dependency on the Vocalization . . . . .	31
2.3.1.3 Measurements Using Bone Transducers . . . . .	33
2.3.2 Modeling the Occlusion Effect . . . . .	35
2.3.2.1 Model for Air-Conducted Transmission . . . . .	35
2.3.2.2 Model for Body-Conducted Transmission . . . . .	37

2.3.2.3	Combined Model for Air-Conducted and Body-Conducted Transmission . . . . .	40
2.3.3	Passive Occlusion Reduction Approaches . . . . .	40
2.3.3.1	Venting . . . . .	41
2.3.3.2	Deep Insertion . . . . .	42
2.3.4	Further Effects Occuring due to Occlusion . . . . .	43
2.4	Occlusion Effect Cancellation . . . . .	44
2.4.1	Concept . . . . .	44
2.4.2	Literature . . . . .	46
<b>3</b>	<b>Filter Design and Optimization</b>	<b>49</b>
3.1	Feedback Control . . . . .	49
3.1.1	Background of Feedback Control . . . . .	52
3.1.1.1	Control Problem Formulation . . . . .	52
3.1.1.2	Sensitivity Functions . . . . .	54
3.1.1.3	Stability . . . . .	56
3.1.1.4	Uncertainty . . . . .	61
3.1.1.5	Nominal Plant Choice . . . . .	68
3.1.1.6	Limitations . . . . .	69
3.1.2	Feedback Controller Design . . . . .	74
3.1.2.1	Mixed-Sensitivity $\mathcal{H}_\infty$ Controller Design . . . . .	75
3.1.2.2	$\mathcal{H}_2$ Control . . . . .	78
3.1.2.3	Controller Design with $\mathcal{H}_\infty$ Optimization . . . . .	78
3.1.3	Controller Post-processing . . . . .	80
3.1.3.1	Order Reduction . . . . .	81
3.1.3.2	Continuous-Time to Discrete-Time Transformations	83
3.1.4	Adaptive Factor . . . . .	92
3.1.5	Summary . . . . .	94
3.2	Feedforward Control . . . . .	94
3.2.1	Time-Invariant Optimal Control . . . . .	94
3.2.1.1	Frequency Domain Ideal Filter . . . . .	95
3.2.1.2	Time-Domain Optimal Filter . . . . .	95
3.2.1.3	Influence of Acoustic Feedback and Measurement Noise . . . . .	99
3.2.1.4	Influence of Uncertainty . . . . .	100
3.2.1.5	Influence of Feedback Control . . . . .	102
3.2.2	Time-Variant Control . . . . .	103



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3.2.3	Summary . . . . .	103
3.3	Hear-Through Equalization Filter . . . . .	104
3.3.1	OEC Structure 0 (Reference Tracking Feedback Controller)	104
3.3.2	OEC Structure 1 (Combined Feedforward-Feedback System)	108
3.3.3	OEC Structure 2 (with Feedback Controller Input Correction)	110
3.3.4	Adjustable Hear-Through . . . . .	113
3.3.5	Relation between OEC and ANC . . . . .	114
3.3.6	Summary . . . . .	116
<b>4</b>	<b>ANC &amp; OEC Systems Implementation</b>	<b>119</b>
4.1	System Components . . . . .	119
4.1.1	Electronic Back-End . . . . .	119
4.1.2	Acoustic Front-End . . . . .	121
4.2	System Measurements . . . . .	122
4.2.1	Electronic Back-end . . . . .	123
4.2.2	Acoustic Measurements Setups . . . . .	125
4.2.3	Use and handling cases . . . . .	125
4.2.4	Secondary Path . . . . .	127
4.2.4.1	Dependency on Fitting . . . . .	127
4.2.4.2	Inter-Person Variability . . . . .	129
4.2.4.3	Dummyhead vs. Human . . . . .	129
4.2.5	Acoustic Feedback Path . . . . .	130
4.2.6	Primary Paths . . . . .	131
4.2.6.1	Dependency on Fitting . . . . .	133
4.2.6.2	Direction-of-Arrival Dependency . . . . .	133
4.2.7	Summary . . . . .	137
4.3	Feedback Controller for ANC & OEC . . . . .	137
4.3.1	Nominal Plant and Uncertainty . . . . .	138
4.3.2	Modeling . . . . .	139
4.3.3	Input-Output Controllability . . . . .	140
4.3.4	Designing the Weighting Functions . . . . .	140
4.3.5	Controller Design . . . . .	142
4.3.6	Order Reduction and Biquad Implementation . . . . .	143
4.3.7	Influence of the Adaptive Factor . . . . .	144
4.4	Feedforward Filter for ANC . . . . .	149
4.5	Hear-Through Filter for OEC . . . . .	153

<b>5</b>	<b>Evaluation</b>	<b>157</b>
5.1	Active Noise Cancellation (ANC)	157
5.1.1	Dependency on Fitting	157
5.1.2	Dependency on Direction-of-Arrival	160
5.1.3	Real-Time Measurements	162
5.2	Occlusion Effect Cancellation (OEC)	164
5.2.1	Listening Test Design	165
5.2.2	Subjective Ratings	167
5.2.3	Objective Measurement Results	169
5.2.4	Correlation of Objective and Subjective Measures	172
5.2.4.1	Regression with Spectral Flatness	173
5.2.4.2	Regression with Relative Spectral Flatness	174
5.2.5	Discussion	175
<b>6</b>	<b>Summary &amp; Outlook</b>	<b>177</b>
6.1	Active Noise Cancellation	177
6.2	Occlusion Effect Cancellation	178
6.3	Real-Time System	179
6.4	Concluding Remarks	179
<b>A</b>	<b>Appendix</b>	<b>181</b>
A.1	Additional Derivations	181
A.2	Additional Background	189
A.3	Measurement Equipment	193
A.4	Occlusion effect	196
A.5	Adaptive Factor	196
A.6	Feedforward controller design	197
A.7	Evaluation of the listening test	200
<b>B</b>	<b>Mathematical Notation &amp; Abbreviations</b>	<b>203</b>
B.1	Mathematical Notation	203
B.2	Mathematical Operators	203
B.3	General Symbols	204
B.4	All Symbols	205
B.5	Acronyms	211
	<b>Bibliography</b>	<b>213</b>